Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 54 (2016) 227 – 232

www.elsevier.com/locate/procedia

6th CLF - 6th CIRP Conference on Learning Factories

A seamless convergence of the digital and physical factory aiming in personalized Product Emergence Process (PPEP) for smart products within ESB Logistics Learning Factory at Reutlingen University.

Beate Brenner[a]*, Vera Hummel[a]

[a]*ESB Business School, Reutlingen University,Alteburgstrasse 150, 72764 Reutlingen, Germany*
* Corresponding author. Tel.: +49 7121 271-3116. *E-mail address beate.brenner@reutlingen-university.de*

Abstract

A seamless convergence of the digital and physical factory aiming in personalized Product Emergence Process (PPEP) for smart products within ESB Logistics Learning Factory at Reutlingen University.
A completely new business model with reference to Industrie4.0 and facilitated by 3D Experience Software in today's networked society in which customers expect immediate responses, delightful experience and simple solutions is one of the mission scenarios in the ESB Logistics Learning Factory at ESB Business School (Reutlingen University).
The business experience platform provides software solutions for every organization in the company respectively in the factory. An interface with dashboards, project management apps, 3D - design and construction apps with high end visualization, manufacturing and simulation apps as well as intelligence and social network apps in a collaborative interactive environment help the user to learn the creation of a value end to end process for a personalized virtual and later real produced product.
Instead of traditional ways of working and a conventional operating factory real workers and robots work semi-intuitive together. Centerpiece in the self-planned interim factory is the smart personalized product, uniquely identifiable and locatable at all times during the production process – a scooter with an individual colored mobile phone – holder for any smart phone produced with a 3D printer in lot size one. Smart products have in the future solutions incorporated internet based services – designed and manufactured - at the costs of mass products. Additionally the scooter is equipped with a retrievable declarative product memory. Monitoring and control is handled by sensor tags and a raspberry positioned on the product. The engineering design and implementation of a changeable production system is guided by a self-execution system that independently find amongst others esplanade workplaces.
The imparted competences to students and professionals are project management method SCRUM, customization of workflows by Industrie4.0 principles, the enhancements of products with new personalized intelligent parts, electrical and electronic self-programmed components and the control of access of the product memory information, to plan in a digital engineering environment and set up of the physical factory to produce customer orders. The gained action-orientated experience refers to the chances and requirements for holistic digital and physical systems.

Peer-review under responsibility of the scientific committee of the 6th CIRP Conference on Learning Factories

Keywords: Seamless, digital cloud-based and physical learning factory, personalized product development, 3D experience software, collaborative interactive environment, Industrie4.0 principles, SCRUM

Peer-review under responsibility of the scientific committee of the 6th CIRP Conference on Learning Factories
doi:10.1016/j.procir.2016.06.108

1. Introduction

The rapid pace at which the world turns today and more importantly will turn in the future – think about the year 2050 [1], certainly poses risks, but offers at least as many great opportunities, because a customer wish or a brainchild born today can be turned into reality in a very short time span.
The next generations [2] (latest Gen Y and Gen Z**) want to create, customize and change – and they have the ideas and digital native [3] knowhow to do so. They hardly differentiate between the virtual and real world; it is simply a seamless transition.
Eminently, the rising multiple technical options will induce people to control things faster and in a better direction, and these are the driving factors behind the new business model of a seamless convergence of the digital and physical factory aimed at a personalized Product Emergence Process (PPEP).
One of these new technical options is the 3DEXPERIENCE business platform of Dassault Systèmes [4]. It provides software solutions for every business segment in the company, from marketing and sales to engineering, and helps companies create differentiating consumer experiences in their value creation process, by means of collaboration, dash boarding and 3D visualization as speech. The App-based end to end cloud software V62015X is the platform used in the ESB Logistics Learning Factory.
The "customer wish" is the smart personalized product - a scooter with an individual colored mobile phone – holder with its own energy supply for any smart phone, produced by additive manufacturing with a 3D printer. Additionally, the scooter is equipped with a retrievable declarative product memory. Monitoring and control is handled by sensor tags and a Raspberry Pi 2 positioned on the product. The engineering design and implementation of the changeable, real and flexible production system is guided by a self-execution system with intelligent conveyor belts, that independently finds, amongst others, esplanade workplaces [5] [6]. Due to the ever increasing complexity of projects, the agile project management method SCRUM [9] has been applied.

2. New business model with reference to Industrie 4.0

Intelligent products, high customization of products, flexible production, highly qualified professionals with a much broader knowledge base, demographically-sensitive job design and individualization of customer requirements are all tags of Industrie 4.0. Society is on its way, with large steps, to the fourth industrial revolution - "Industrie 4.0". This announces a technologically advanced industry by means of complex cyber-physical systems, distinguishing between intelligent products and beyond smart factories [10]. Cyber-physical systems are networked systems that act autonomously and remodel the entire value chain of products. Together with cloud computing, cyber-physical systems are the cornerstone of the fourth industrial revolution [11]. In this area, employees are part of a new business model, working in office 21 room zones with digital tools, networked worldwide, handling the data on cloud systems, designing and implementing in the digital world before transferring it into the physical environment, using agile project management methods and creating smart individual products and flexible intelligent factories all in order to speed up the customer delivery process.

2.1. 3D Experience Platform

The 3D Experience platform of Dassault Systèmes [4] is a possible software solution supporting new business models with reference to Industrie 4.0 implemented in the ESB Logistics Learning Factory- engineering and operating cockpit. 219 roles such as that of a "contract deliverable manager" or "visual experience designer" are integrated with special functionalities.

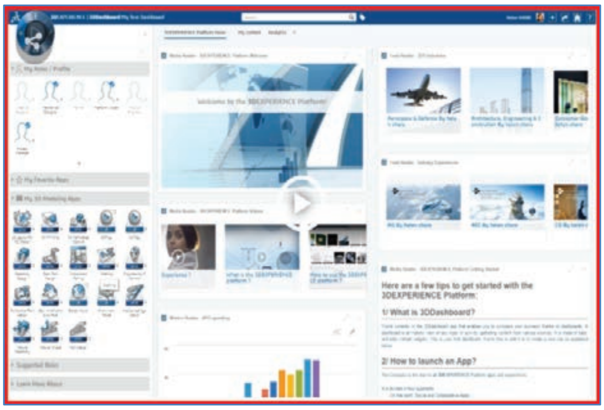

Fig. 1 Surface of cloud based 3D experience software

2.2. Research question

The research question, which was supposed to be answered, can be divided into three sub-questions, out of which the first one is rather an applied research project:
Firstly: Design and production of a smart, personalized, multi-variant product, to implement the first version of a seamless digital and real factory through available ICT technologies and flexible production technology concerning Industrie 4.0 aspects.
Secondly: Can the implementation of a seamless transition between the digital and physical factory accelerate the delivery lead time for personalized products?
Thirdly: Can students and/or seminar participants gain knowledge and skills about the chances and requirements of planning, implementing and maintaining a seamless convergent digital and physical factory in time-limited seminars?

3. Information and Communication Technologies (ICT) with agile project management method (SCRUM)

To ensure that projects do not collapse due to their increasing complexity or the reluctance of employees and students to share their knowledge, the agile project management method SCRUM [12] was introduced in the ESB Logistics Learning Factory.

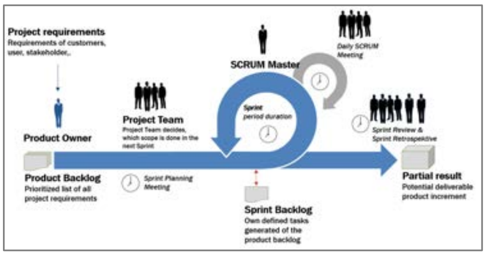

Fig.2 Agile project management method SCRUM

A movement from rigid structures to an agile culture was completed using the visualization of the **product backlog** with product owner acceptance criteria and cost estimate with story points; the **sprint backlog** with tasks, status and remaining work hours; the **impediment backlog** with obstacles as an instrument to escalate; the **task board** published in the printout format A1 to show the rate of progress of the sprint backlog; and the **burndown chart** with the graph on the zero line at the end of the planned project duration. The roles are played by one or two **product owners** who could be a customer or a factory owner, or in the master project in question, the professor and the project coordinator; a **scrum master** of the student group who must ultimately make project-related decisions but without managerial authority; and the **project team** – a group of students, ideally not more than seven persons who are able to subdivide the complete work content of the project in the sprint backlog. Daily SCRUM meetings and almost weekly review meetings are factors of a successful result, supported by mobile devices such as tablets and smart phones with WhatsApp groups located in the ESB Logistics Learning Factory (LLF) in rooms for project working, brainstorming, relevant ideas and problem solving, SCRUM meetings and internal conferences.

4. Personalized Product Emergence Process (PPEP) for the smart personalized product, development and manufacturing

The customer requirements alone were crucial for the development of the product – the scooter with two individual components namely a cell phone holder with its own power supply, and a retrievable declarative product memory.

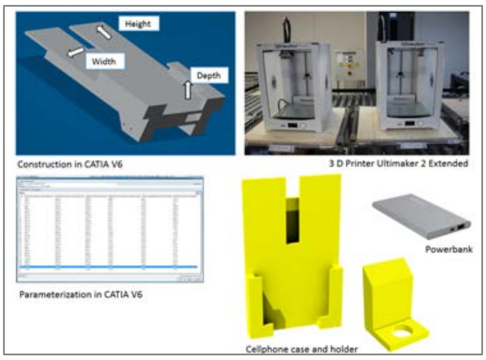

Fig.3 Development and additive manufacturing of the personalized product

For the mobile phone holder, 4 different colours and 32 possible phone designs by Apple, Nokia and SAMSUNG were given as guideline alternatives by the product owner. The product memory should be placed on the scooter and the information gathered should be clearly visibly available. To achieve these goals the phone holder was constructed in CATIA V6 with parameterization in the form of a design table and manufactured with 3D printer Ultimaker 2 Extended.

The active product memory [13] was programmed on a Raspberry Pi 2. Fundamentals of this active product memory are the intended use for manufacturers, merchants and end customers, recording of relevant product and operating data, analyzing and interpreting sensor data and last but not least an active exchange of information between the environment and users e.g. direct feedback via LED or display. The realization was done for the detection of environmental effect data e.g. icing by a python script for retrieval; remote analysis; and dissemination of sensor data. The “warning or go”- information of the translated data was given out on a LCD display.

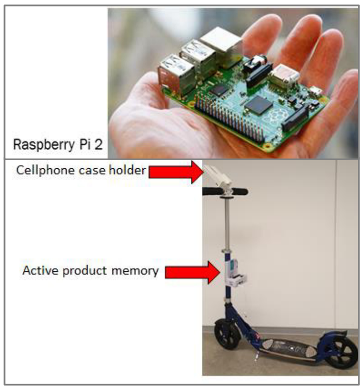

Fig.4 Real product scooter with cellphone case holder and active product memory Raspberry Pi 2

5. Digital and physical ESB Logistics Learning Factory

The LLF is equipped with a continuously integrated product and process planning environment (so called “Engineering & Operations Cockpit (EOC)”) as well as various kinds of physical infrastructure, allowing for the design of realistic work and logistics systems. Based on the defined products and customer orders this learning environment allows the participants to plan, validate, realize and optimize a production system holistically. The “EOC” relies mainly on tools for product and process engineering as well as for operations management.

The engineering consists of different tools [14] of the software company Dassault Systèmes, such as the centerpiece CATIA for computer-aided design, ENOVIA for product data management and DELMIA for process and resource planning and simulation, so that most of the required data and functionalities are integrated into a single platform, and programming of software interfaces can be avoided. In addition, different production scenarios can be planned and validated with comparatively low effort and within a short period of time. Before the changes are executed in the physical factory environment, the gathered information from the shop floor level is aggregated, analyzed, interpreted and integrated into planning to optimize and restructure the production system digitally.

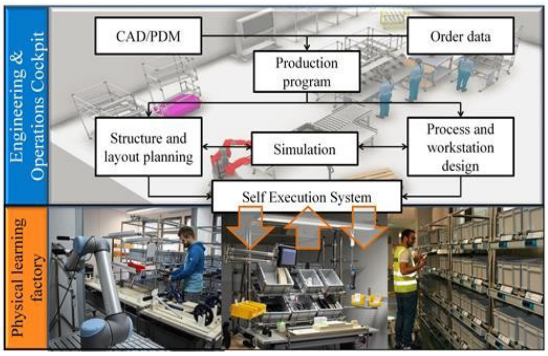

Fig. 5 Digital planning environment and physical learning factory

The digital learning factory environment can also be used to initiate rescheduling actions or to introduce turbulences (e.g. high priority customer orders from the online shop, malfunctions of infrastructure or resources etc.) which have to be solved manually by the participants or semi-automated by the respective planning and control systems of the EOC.
To ensure an improved support of changeable production scenarios and decentralized control structures [15] a cloud-based so-called “Self-Execution System (SES)” framework has been developed in cooperation with the IT company BECOS.

5.1 Digital Engineering processes

Nowadays, the customization of workflows regarding Industrie 4.0 principles has already started. For a working scenario in the LLF, the idea was posted in the **social network App** 3DSwYm and proven as an idea portal online. Change of information across organizations, with a focal point on knowledge and value creation, communities for interdisciplinary communication and the transfer of data for each member takes place in this App. The scooter project was generated in the **project management APP** of ENOVIA. Project decisions and controls, targets, schedules, milestones, contract contents as well as chat and collaboration functionality was performed therein. The design data of the scooter was migrated and opened in the **design App** of CATIA from a legacy V6 system with a 3DXML file. The parameterized cell phone holder was designed with a design table in a **construction APP** of CATIA. The assembly processes were loaded in the **process planning App** of DELMIA. The labor system was automatically created with stations and jobs in the line with the EBOM. The MBOM is generated when assemblies are combined and the product is linked to the process.
The design phase of the 3D layout was executed in the plant layout application by implementing resources, workers, conveyor belts etc. partial from catalog libraries. The time analyses for the operations were defined with the UAS process with the **time analysis APP**. The line balancing is automatically calculated in the **workload balancing App**. The shoring simulation of the product is launched on the **Play button** in the compass of the software and determines the assembly or the traverse tracks. The simulation of the working system was initiated in the **process planning App** after the definition of the precedence relations and passing direction.
The work instructions for the blues were generated with film sequences and their respective screenshots with marking in the **work instructions App** . In addition, utility films were used at the workstations.

Fig.6 Digital Factory represented in the 3D Experience software

5.2 Physical Learning Factory

Following the focus of the LLF, a large variety of assembly and logistics infrastructure is available for the participants to implement and optimize production systems.
Assembly system
A modular pipe construction system can be used by the learners to build various kinds of customized physical infrastructure such as assembly, quality check and packaging workstations. All installations can be reconfigured or optimized easily, e.g. to resolve ergonomic issues identified by the learners during the workshop. Since all workstations are mobile and equipped with wireless communication technology and accumulator batteries, there are no limitations regarding changes to the factory layout. The workers at the assembly stations can use mobile tablet-pc`s, e.g. to receive orders, to send information back to the planning system, to access multimedia-based work instructions or to analyse specific production processes. The access or feedback of information can take place manually or automatically, e.g. by using RFID-technology embedded on the

product itself or on the jigs. For storage purposes, racks for boxes and pallets can be created using the modular pipe system already mentioned. Besides manual pallet trucks and transport trolleys, different kinds of autonomous guided vehicles (AGVs) as well as an intelligent continuous conveyor system are available for material transport. By means of the plug-and-play functionality and local control units in each conveyor module, the modules can be combined to user-defined conveying lines without the need of a central control entity.

Human-Machine-Interfaces (HMI)

To automate specific process or to facilitate the work of the workers, two collaborative robots ("Rethink Robotics Baxter" and "Universal Robots UR10") can be implemented into the work system. Through sonar and tactile sensors, these robots are able to collaborate with workers without protective fences. These robots can also be taught directly by moving the robot joints, which allows these robots to be integrated quickly for specific tasks directly by the worker. Learners are therefore able to experience the potentials and limitations of collaborative robots, which should not replace the worker but assist him/her in a practice-oriented manner and examine the effects of this technical assistance system on the capacities, throughput times or physical strain of selected work tasks. For more complex tasks, these robots can be also programmed via the open-source framework ROS.

Fig.7 ESB Logistics Learning Factory

Additive manufacturing technology

The realization of the product idea was achieved via the additive manufacturing process. The characteristics quality, process quality, temperature stability and building space were decisive for the purchase of two 3D printers. The model Ultimaker Extended 2 meets the requirements excellently and is also suitable for the living room, because the fused deposition modelling is very quiet. To implement the 3D printing process into the production scenario, the material – filament PLA (Polylactid), must first be determined. The optimal printing parameters were specified in the slicing software Cura. The printing time for the holder is approx. 6 hours and for the cellphone case approx. 15-18 hours. Thus, the bottleneck in the production is identified, keeping in consideration the period assembly of the scooter of about 7 minutes. The processes employed in the LLF are **Rapid Prototyping** in the product development phase and **Rapid Tooling** for the construction of mounting devices.

6. Results and lesson learned

The overall concept regarding the knowledge and competence development within the LLF is composed by defined learning goals, the corresponding learning contents, strategies to achieve action competence and the learning environment which covers digital tools for an integrated product and process planning and the physical infrastructure to realize the developed solutions.

To achieve the given objective, here the research questions, of providing the learner with the relevant skills and competences, a multi-staged qualification concept is used. This concept contains phases of self-study, instruction, practice and the self-dependent action and experience oriented application of methods within a comprehensive and complex project in the learning factory. The objective evaluation of the execution of the given task can be conducted based on specific indicators such as capacity utilization, throughput times, quality performance indicators, on-time delivery or other relevant measures such as personalized product design depending on the learning goals. But more important than these objective criteria is the reflection of the learners group regarding the learned methods, the decisions made and the exchange of individual experiences according to the adopted role within the team.

It was an extensive project. The first component of the research question was to design and produce a smart personalized product with variants, to realize the first version of a seamless digital and real factory with innovative ICT technologies and a hybrid intelligent production systems concerning Industrie 4.0 aspects was peripherally achieved. The personalized product part has more than 100 variants. An extensive amount of training was required, especially in the field of the digital tools. The students learnt to understand the principle of intelligent product, customization as well as the necessity of consistent product, process and resource data.

The reflection process with all participants showed that:

- They had the impression to understand for the first time what could be meant by Industrie 4.0 and the aspects of intelligent products, self-steering systems, and seamless processes between the digital and physical world.
- They could gain competences and experiences in using an engineering system integrated in one platform without any interfaces.
- They experienced that even having a comprehensive 3D Experience System with apps and predefined roles, a lot of preparation and knowledge in using the tools is required.
- They learnt how important it is to have correct data throughout the entire process chain.
- Having done all the design and conceptual work with the digital tools and proven the concept in the virtual environment, a fast ramp-up of knowledge was possible. No trial and error actions were required.
- Validation of the digital solution is mandatory and the structure of the real factory may still pose challenges which are not noticed in the digital world.
- By having designed a parameterized product, customer specific orders can be produced rapidly.
- Having realized a seamless digital and real factory with

ICT technologies, a flexible intelligent production change and adaption to new requirements can be made faster.

- A cloud solution is not always the best solution: If the cloud becomes unreachable for reasons such as server problems and no back-up means of data storage has been employed, there is no data for your production of the personalized product. A cloud system alone is thus insufficient.

The development of the learners occurs through the gradual increase of technical, social and methodological skills aiming in concrete actions. The issues regarding the realization of the project initiate individual learning as a result of a motivating agile labor procedure. The learners and learning guides meet nearly as equal persons and share and enlarge their knowledge in a common educational process.

By using the principle of the parameterized cell phone holder in the construction APP of CATIA and thus the immediate presence of all further required information, it can therefore, in response to the second research question, be concluded that the delivery time to the customer can be shortened drastically. Immediately after the customer order is received, the production file for the 3D printer, the pull list for the set-building and the supportive work instructions are prepared. A real-time capability is having the information available for steering the order towards the available production resources.

In response to the third and final research question, the application of this comprehensive 3D Experience System containing CAD- CATIA, PDM- ENOVIA and DELMIA for process and resource planning and simulation, showed that students and participants in future seminars require experience or extensive training in using these tools as a pre-condition for successful learning. This could possibly be replaced by providing a so-called reference system (digital–physical-basis-scenarios) with predefined starting positions.

8. Conclusion

Next steps for the digital factory are to enhance the factory layout, to integrate the human ergonomics functionalities, to teach the robots by definition of the kinematics etc. The existing digital learning factory covering hybrid assembly systems will be extended for changeable hybrid manufacturing systems (subtractive and additive technologies).

For goal oriented application, dedicated learning modules which will comprise of the digital engineering and physical production - the so called digital–physical -basis-scenarios - must be developed and filled with reference data. This will enable the participants in time-constrained seminars to learn action-oriented, the opportunities and risks posed by a seamless convergence of the digital and physical factory consisting of such powerful comprehensive engineering tools such as 3D experience and innovative production technologies in context of Industrie 4.0. In addition, a review method specifically for “a seamless digital and physical factory” will be developed to evaluate with qualitative and quantitative indicators the learning success of the dedicated modules and seminars.

References

** Born as from 1980 Gen Y and 2000 Gen Z

[1] Die Generation Y – Mitarbeiter der Zukunft. Herausgeber Anders Parment. Gabler Verlag ISBN-10: 3834915904.
[2] http://www.news.de/panorama/855311889/arbeit-und-leben-in-der-zukunft-deutschland-im-jahr-2050/5/.
[3] http://www.manager-magazin.de/unternehmen/it/a-625126.html.
[4] http://www.3ds.com.
[5] Wegener D. Industrie 4.0 – Chancen und Herausforderungen für einen Global Player. In: Bauernhansl T, ten Hompel M, Vogel-Heuser B, editors. Industrie 4.0 in Produktion, Automatisierung und Logistik, Anwendung, Technologien, Migration. Wiesbaden: Springer Vieweg; 2014. p. 342-358. http://www.scinexx.de/business-16962-2013-12-04.html.
[6] Der Weg zur modernen IT-Fabrik. Industrialisierung – Automatisierung – Optimierung Herausgeber: Abolhassan, Ferri (Hrsg.) Springer-Gabler Verlag ISBN 978-3-658-01483-4.
[7] VDI Verlag GmbH (Hrsg.) (2012, URL): Industrie 4.0 braucht effiziente IT-Sicherheit, http://www.ingenieur.de/Themen/IT-Sicherheit/Industrie-40-effiziente-IT-Sicherheit (03.09.2013).
[8] Information and Communication Technologies and Real-Life Learning, Herausgeber van Weert, Tom J. Tatnall, Arthur. Springer Verlag ISBN 9781461498179.
[9] SCRUM Agile IT - Projekte erfolgreich gestalten, Jonathan Brandstäter 2013 (ISBN 978-3-658-04429-9, ISBN 978-3-658-04430-5 (eBook))
[10]Scheer, August-Wilhelm (2013): Industrie 4.0 – Wie sehen Produktionsprozesse im Jahr 2020 aus?, IMC Verlag, Vorwort.
[11]Marktplatz Mittelstand GmbH & Co. KG (URL): Industrie 4.0 – Fabrik von morgen: Vernetzung von Produktion und IT von 2013, http://www.unternehmer.de/management-people-skills/ 150808-industrie-4-0-fabrik-von-morgen-vernetzung-produktion-it (03.09.2013).
[12]Scrum - Einführung in der Unternehmenspraxis. Von starren Strukturen zu agilen Kulturen Herausgeber Dominik Maximini. Springer Gabler Verlag ISBN 978-3-642-34822-8.
[13]Jens Haupert. The pivis framework for visualization of digital object memories.In Proceedings 2011 Seventh International Conference on Intelligent Environments (IE 2011). International Conference on Intelligent Environments (IE-11), July 25-28, Nottingham, United Kingdom, Seiten 179–185. IEEE Computer Society, 7 2011.
[14 Schubert, Viktor (URL): FZI Forschungszentrum Informatik: Product Lifecycle Management -Systeme, http://www.plmportal.de/index.php?id=904 (07.10.2013).
[15]Fabrikplanung und Fabrikbetrieb. Methoden für die wandlungsfähige, vernetzte und ressourceneffiziente Fabrik Herausgeber Michael Schenk, Siegfried Wirth und Egon Müller. Verlag Springer Vieweg. ISBN 978-3-642-05458